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MUNICIPALITY OF METROPOLITAN SEATTLE

Seattle, Washington

SPECIAL DUWAMISH RIVER STUDIES

WATER QUALITY SERIES
NO. 1

BY
GARY W. ISAAC, *Ecological Analyst*
GLEN D. FARRIS, *Senior Water Quality Analyst*
CHARLES V. GIBBS, *Chief, Water Quality Control Division*

FEBRUARY 1964

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MUNICIPALITY OF METROPOLITAN SEATTLE
SEATTLE, WASHINGTON

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No. 1

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FORWARD

The Municipality of Metropolitan Seattle (Metro) is a federation of local governmental entities, formed for the purpose of ending the threat of water pollution in the Metropolitan Seattle area. In 1959, Metro embarked on a program of sewerage construction which, by 1972, will involve expenditures of about $135,000,000. At that time, over 50 miles of large interceptor sewers and four new treatment plants will be in operation. Two of the plants, Renton and West Point, will be the largest of their type in the Pacific Northwest.

With Metro committed to clean up the environmental waters, it was deemed necessary that a means of evaluating the effectiveness of the program be initiated. Therefore, monitoring of the receiving waters was started in 1961. In addition to proving results, the monitoring program will: provide a basis for design according to specific needs; permit gearing of future projects and construction schedules to actual, demonstrated needs; provide a basis for controlling operations to produce required end results; fix the responsibility for adverse conditions caused by other waste dischargers and insure compliance with the requirements of the State regulatory agencies.

We are pleased to present this publication as the first of a series of reports relative to the results of the water quality monitoring program.

Harold E. Miller
Executive Director

SPECIAL DUWAMISH RIVER STUDIES

ABSTRACT

Degradation of water quality in the Duwamish Estuary became apparent in August, 1963. To monitor changes in river conditions during this period, an intensive sampling program was undertaken. The influence of tide, river flow, vertical mixing, upwelling and diurnal fluctuations in water quality were studied throughout the critical period by daily sampling and 24-hour studies. River flow and upwelling were found to be of minor importance. Tidal stage and total tidal exchange were found to correlate closely with changes in water conditions measured in the estuary. The importance of these tidal parameters in any program for predicting impending water pollution problems is discussed.

INTRODUCTION

The Green-Duwamish River system has played an important role in the history, present economy and planned future development of the metropolitan Seattle area. The first sawmill in King County was built in 1854 on the fertile flood plain of the Black and Cedar rivers, which were tributaries of the Duwamish at that time. Before rail connections were made between Renton and Seattle, a major portion of product shipment was made through the Black River into the Duwamish and hence, to Elliott Bay.

Originally, the Green-Duwamish drained an area exceeding 1,600 square miles, consisting of the White, Green, Black, Cedar and Lake Washington drainage basins (see insert, Figure 1). The river was known as the Green River from its source to its confluence with the Black River, beyond which it was known as the Duwamish. In 1906, a severe flood permanently diverted the White River into the Puyallup River system, and with the diversion of the Cedar River into Lake Washington and the closing of the Black River brought about by construction of the Lake Washington Ship Canal, the Duwamish drainage basin was reduced to its present 474 square miles. Throughout the change in drainage areas, the nomenclature has remained unchanged; consequently, the system is still known as the Green-Duwamish. The reduction in drainage area has had no noticeable effect on the economic worth of the system, but has changed the flushing ability of the stream. One of the major resources of this drainage system is fisheries, which, in 1957, represented a $1,000,000-a-year income from sport and commercial stocks spawned and reared in the upper Green River. A

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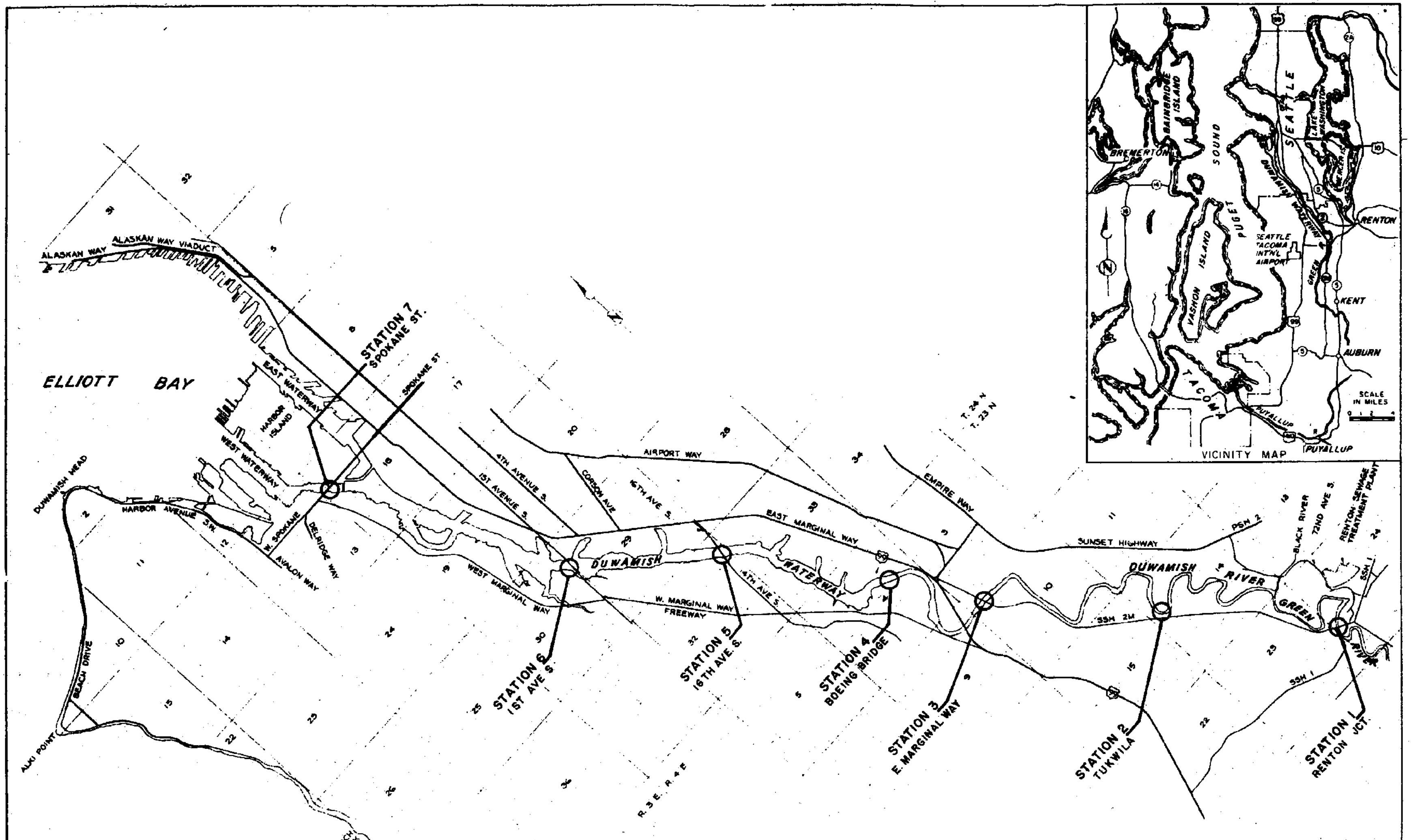

FIGURE 1

LOCATION OF SAMPLING STATIONS ON GREEN-DUWAMISH RIVER SYSTEM found to be approximately 26,000 pounds of BOD per day, most of which was being introduced into the estuary. The 1955 study by the PCC indicated that treated domestic sewage was entering the river at Auburn, Kent and Seattle and that raw sewage was entering the estuary from numerous outfalls and overflows. Ten organic industrial wastes and thirteen toxic industrial wastes were being discharged into the river. The 1957 University of Washington study reported temperature and DO conditions to be critical for fish passage through the estuary and suggested that "a policy of removing significant amounts of untreated sewage from the lower river should be included in any sewage program proposed for the King County-Seattle metropolitan area."

THE LONG-TERM DUWAMISH PROGRAM

A pollution abatement program was proposed in 1958 after a two-year study by consulting engineers who had been retained by the State, King County and the City of Seattle. The program was designed to eliminate pollution from all environmental waters of the greater Seattle area and included, as one important facet, rehabilitation of the Green-Duwamish River. The long-range plan calls for the removal of domestic and industrial waste discharges from the lower Green River and the Lake Washington drainage basins. These wastes will receive secondary treatment at a new facility near Renton with subsequent discharge of the treated effluent into the river near Black River Junction. In addition, all discharges into the Duwamish River will be intercepted and conveyed to the new West Point treatment plant for treatment and disposal directly into Puget Sound.[4]

To implement the program, the voters of the greater Seattle area, in 1958, formed the Municipality of Metropolitan Seattle (Metro). Construction on the project was started in 1961 and will be completed in 1971.

To determine the effectiveness of the program, an evaluation of the present extent of pollution was necessary. Thus, Metro has undertaken, in cooperation with the United States Geological Survey, an extensive study of the physical, chemical and biological characteristics of the lower Green River and the Duwamish Estuary.[5] As an integral part of this program, four automatic water quality monitors are presently being installed along the river.. These automatic units will continuously record values of five water quality parameters and telemeter results to a central laboratory for examination. These units will be placed in operation in early 1964 and will materially augment the existing manual sampling program which was instigated by Metro in 1961. The results of a small portion of this sampling program will be discussed in this report.

SPECIAL STUDIES, SUMMER 1963

On August 6, 1963, a routine sampling trip revealed that the bottom waters of the Duwamish Estuary lacked adequate amounts of dissolved oxygen to maintain aquatic life for any prolonged period. Original investigations by the PCC, the University of Washington and by the Metro staff had indicated that this low DO condition may have been prevalent during the late summer for many years. Values approaching critical levels had been obtained by Metro in 1961 and 1962. However, when a value of 4.0 mg/l was obtained near the bottom at 16th Avenue South on August 6, 1963, there was immediate concern over the possibility of further degeneration during the period of adult salmon migration (August through October). Based on this observation, the Metro staff began a program of daily sampling during the critical summer period. Station 5 (16th Avenue South) was selected for this intensive sampling as it has historically represented the location of the oxygen sag in the Duwamish Estuary. Figure 2 shows the mean bottom DO concentrations obtained from samples collected on weekly river trips during four seasons - late summer and mid-winter, 1962, early spring and late summer, 1963. During each of these periods, the lowest mean DO concentrations were obtained near Station 5. Figure 3 presents the bottom DO values obtained from river trips during the summer period of 1963. The month-by-month degeneration in oxygen concentration through the summer period is apparent. At Station 5, bottom DO's decreased from 5.2 mg/l on July 9 to 3.1 mg/l on September 4.

DIURNAL STUDIES

Weekly sampling of river conditions has been carried out on a schedule that is independent of tidal stage and time, although these conditions have been recorded. The sampling schedule was arranged so that over a long period, all tidal phases would be sampled and, consequently, the influence of tide could be evaluated. To quickly determine the tidal stage that needed special attention, and with insufficient background data upon which to rely, diurnal studies to ascertain the importance of tidal variation were necessary. Two such studies were conducted at Station 5, one

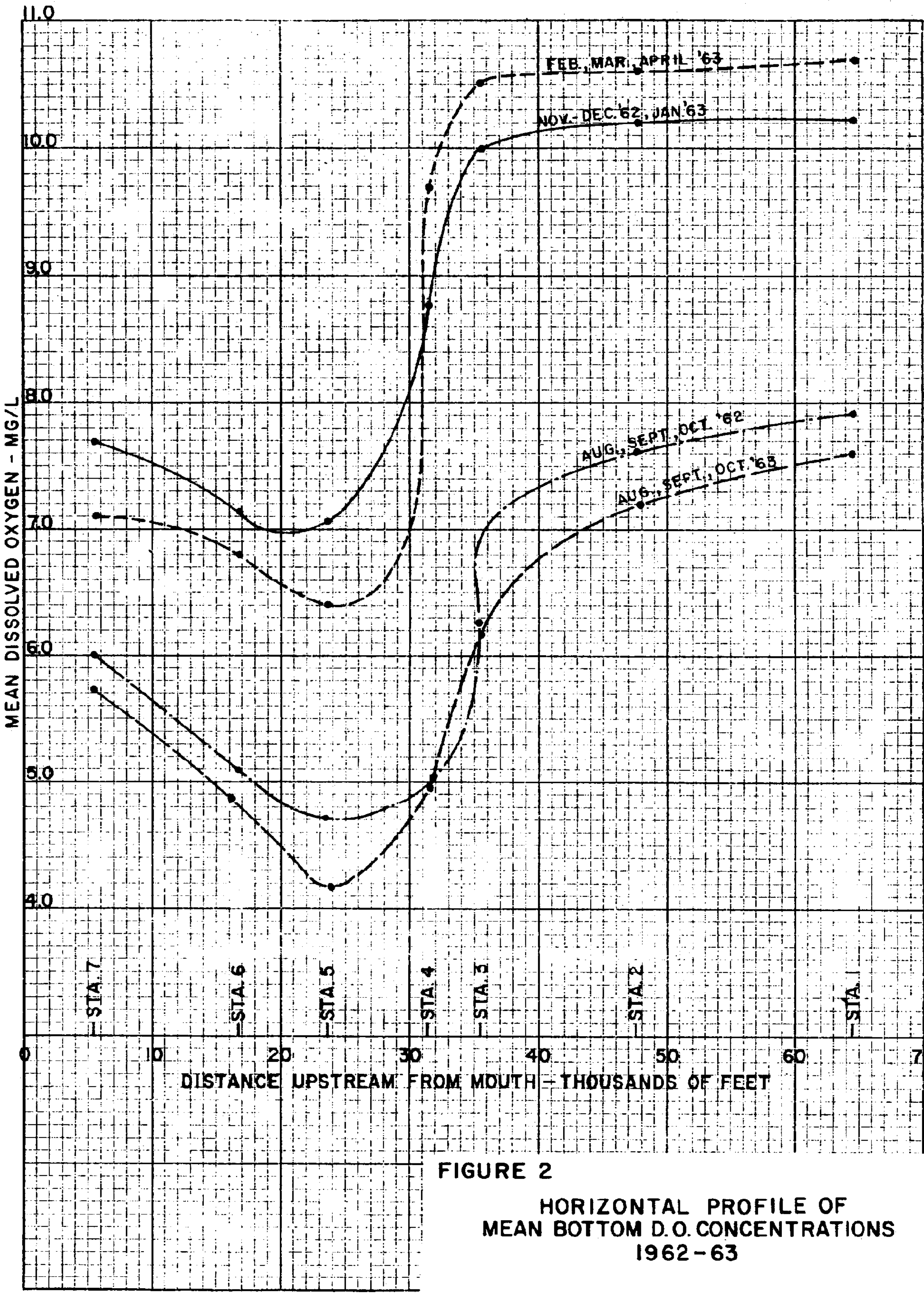

FIGURE 2

HORIZONTAL PROFILE OF
MEAN BOTTOM D.O. CONCENTRATIONS
1962-63

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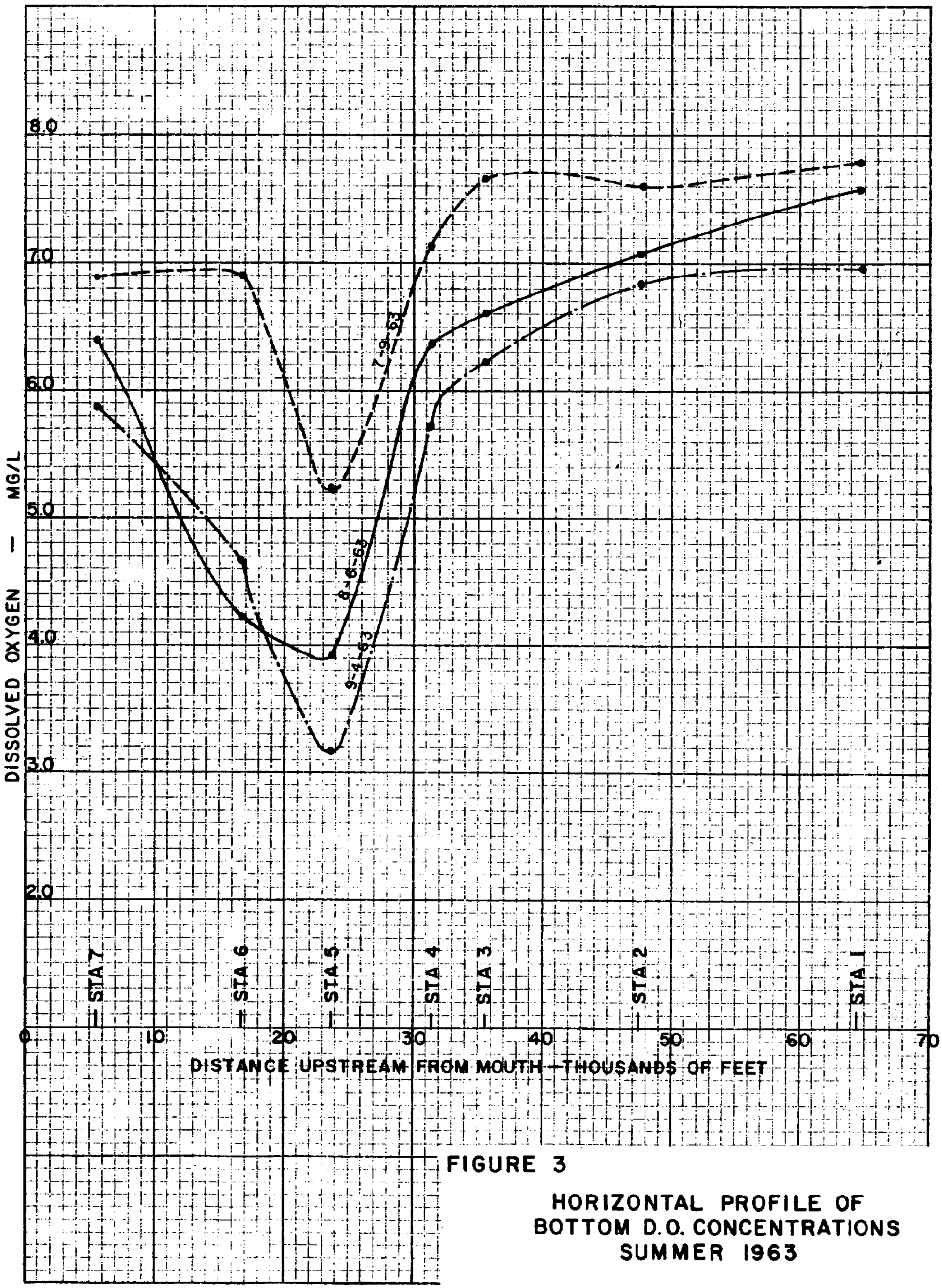

FIGURE 3

HORIZONTAL PROFILE OF
BOTTOM D.O. CONCENTRATIONS
SUMMER 1963

on August 8-9 and another on August 19-20, 1963. Samples were taken near the surface and bottom at 15-minute intervals for a minimum of 24 hours. Parameters measured included dissolved oxygen, conductivity, and temperature. Dissolved oxygen in mg/l was determined by the Alsterberg modification of the Winkler method;[7] conductivity in micromhos and temperature in °F. were determined with an Industrial Instruments Model RB2334I conductivity meter. Chloride concentrations in mg/l were determined from chloride versus conductivity curves prepared in the laboratory using samples of Duwamish River water.

The relationship of these parameters to tidal stage is presented in Figures 4-9. Information used to plot the time and height of the tides for both diurnal surveys was obtained from the 1963 tide tables of the United States Department of Commerce, Coast and Geodetic Survey.[8] Tides were computed from the Seattle reference station and the indicated correction applied for Eighth Avenue South on the Duwamish Estuary. It should be noted that diurnal inequality is one of the chief characteristics of Pacific Coast tides, i.e., the difference in heights of successive high waters or low waters. In general, the largest inequality is for low waters, but for Seattle tides in particular, there may be as much as a four foot difference between successive highs and eight feet between successive lows (see Figures 4 and 5).[9] Tidal fluctuations and river flows on the days of the diurnal studies were similar so that direct comparison of the results was possible.

The relationship of per cent DO saturation to tide is presented in Figures 4 and 5.[10] Of particular significance is the direct relationship between bottom per cent saturation values and

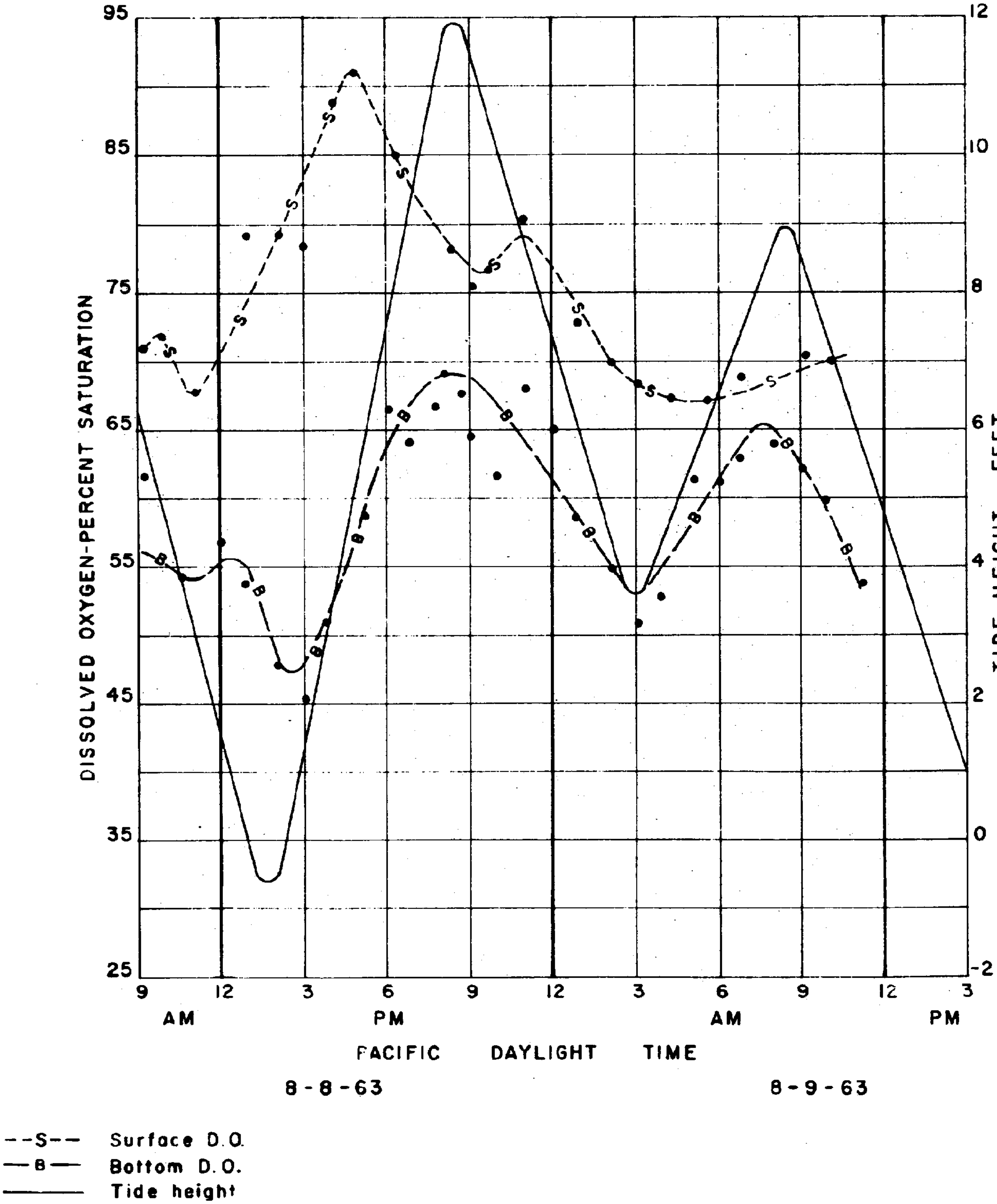

FIGURE 4

FLUCTUATIONS IN SURFACE AND BOTTOM DISSOLVED OXYGEN WITH CHANGES IN TIDE HEIGHT - STA. 5

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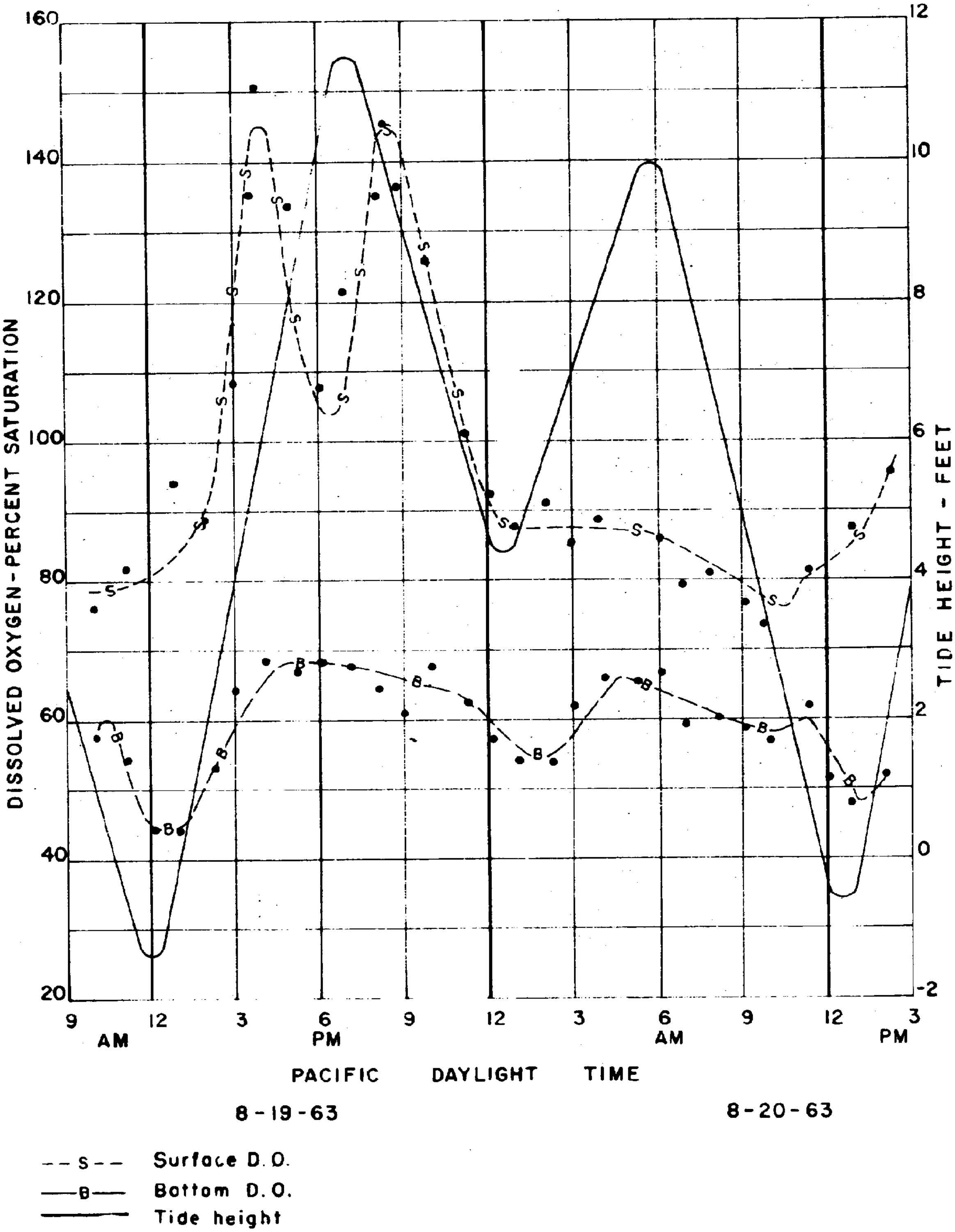

FIGURE 5

FLUCTUATIONS IN SURFACE AND BOTTOM DISSOLVED OXYGEN WITH CHANGES IN TIDE HEIGHT - STA. 5

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tide phase. The bottom DO values, in particular, follow the tide very closely with the minimum values occurring shortly after lower low water. Presumably, as the tide floods into the estuary, oxygen-rich water from Puget Sound passes the sampling point, and DO values increase markedly. As the tide ebbs, the bottom water, upon which a significant BOD has been exerted, decreased rapidly in DO concentration. As previously discussed, wastes containing over 26,000 pounds of BOD are discharged into the river each day. A large portion of this demand is discharged into the lower estuary where mixing with the incoming salt water is possible. In addition, benthic samples taken with an Eckman dredge were found to be extremely rich in organic matter and apparently producing hydrogen sulfide, resulting in further depletion of the oxygen resource.

The tide also exerts considerable influence on the surface DO values. During both diurnal studies, surface DO values were maximum before higher high water. The DO level dropped at high slack and then increased sharply again before beginning the steady decline on the ebbing tide. The surface pattern is undoubtedly obscured by the influence of such factors as photosynthetic activity, turbidity, temperature and river flow, plus the fact that due to density, certain wastes tend to layer in the surface waters. Despite other surface influences, a consistent relationship between surface DO and tide exists.

Tidal phase also has a pronounced effect on the variation in surface and bottom chlorinity as is shown in Figures 6 and 7. Chlorides are lowest on the ebb at both the top and bottom, and are at a maximum near high slack. There appears to be a more

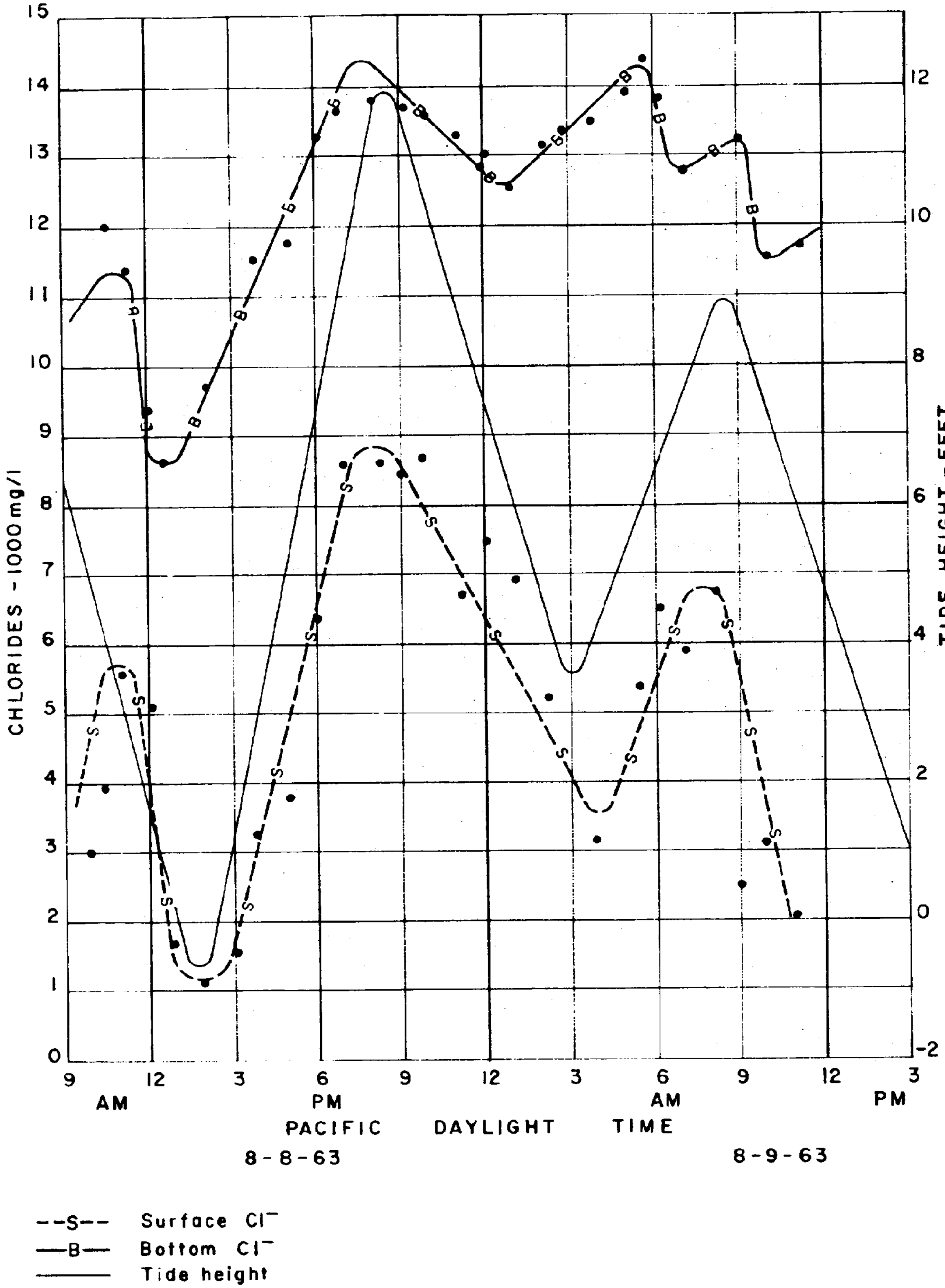

FIGURE 6

FLUCTUATIONS IN SURFACE AND BOTTOM CHLORIDES WITH CHANGES IN TIDE HEIGHT - STA. 5

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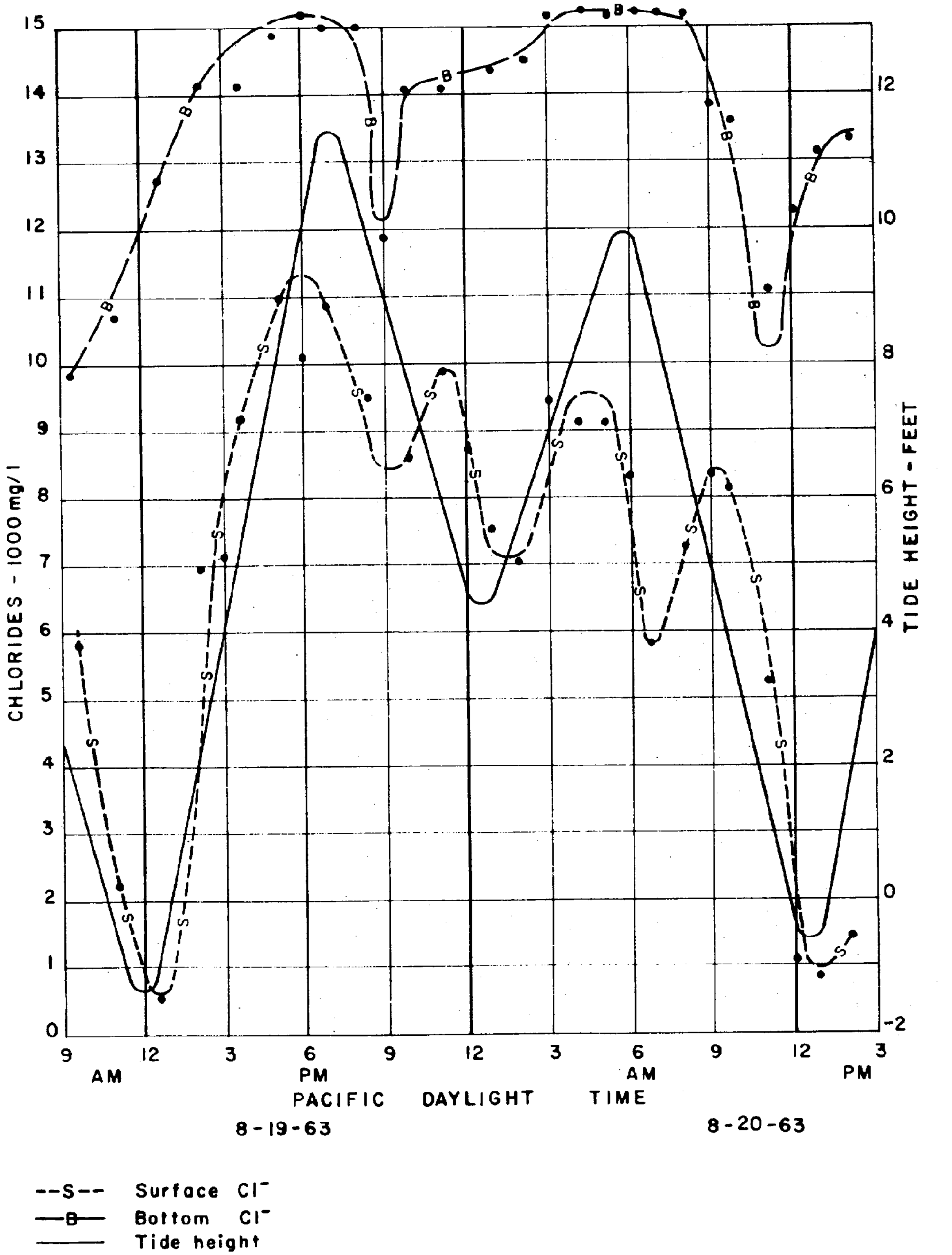

FIGURE 7

FLUCTUATIONS IN SURFACE AND BOTTOM CHLORIDES WITH CHANGES IN TIDE HEIGHT - STA. 5

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SEA421275

pronounced influence of lower high water upon chloride ion concentration than was evident with per cent saturation of DO. The influence of the Duwamish River is also noticeable in Figures 6 and 7. As the tide ebbs, the river influence is at its maximum and consequently the chlorinity is low; as the tide floods, some mixing into the upper layer by the more saline Elliott Bay water is evident and chlorinities increase.

The influence of tide in the regulation of water temperatures is shown in Figures 8 and 9. During the summer period, incoming salt water is colder than the river water. Warmest water temperatures are consequently found on the ebb when the influence of the river is maximal and coldest temperatures are extant on the flood when the influence of Puget Sound waters is greatest. Again it is apparent that the higher high water and lower low water stages play an important role in the regulation of variations in water quality.

PROFILE STUDIES

To augment the diurnal studies, vertical profiles were taken to determine the change in water quality with depth. The results of two of these profiles taken near lower low water on September 5 and September 16, 1963 are plotted in Figures 10 and 11. Both of these profiles show that the maximum depth to which there is appreciable vertical mixing at low tide is approximately eight feet. Below this point the water mass is very uniform, and undoubtedly this uniform zone represents the depth of the salt water wedge at this location. The depth of the zone in which the dissolved oxygen concentration was 5 mg/l or higher, as recommended

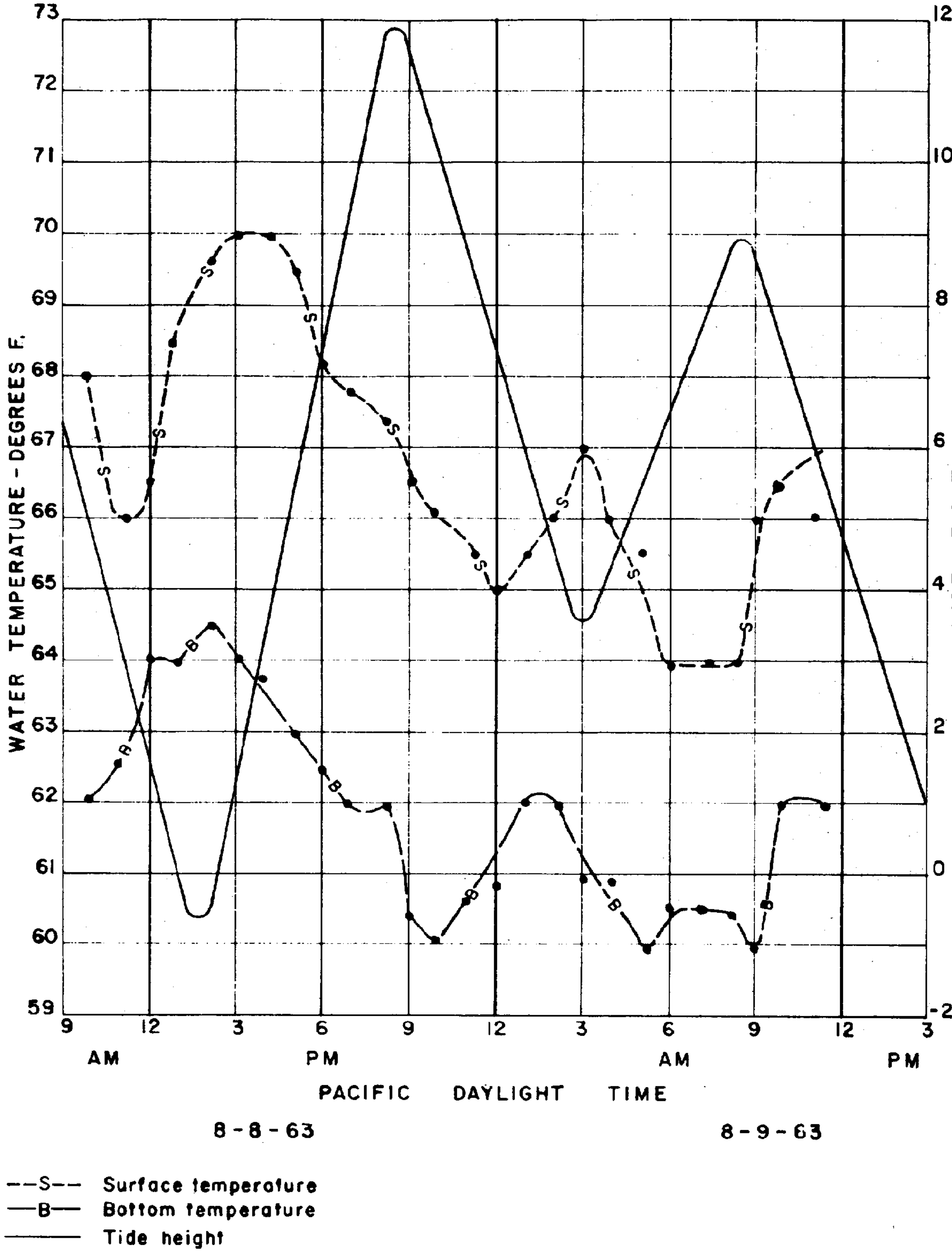

FIGURE 8

FLUCTUATIONS IN SURFACE AND BOTTOM WATER TEMPERATURE WITH CHANGES IN TIDE HEIGHT-STA. 5

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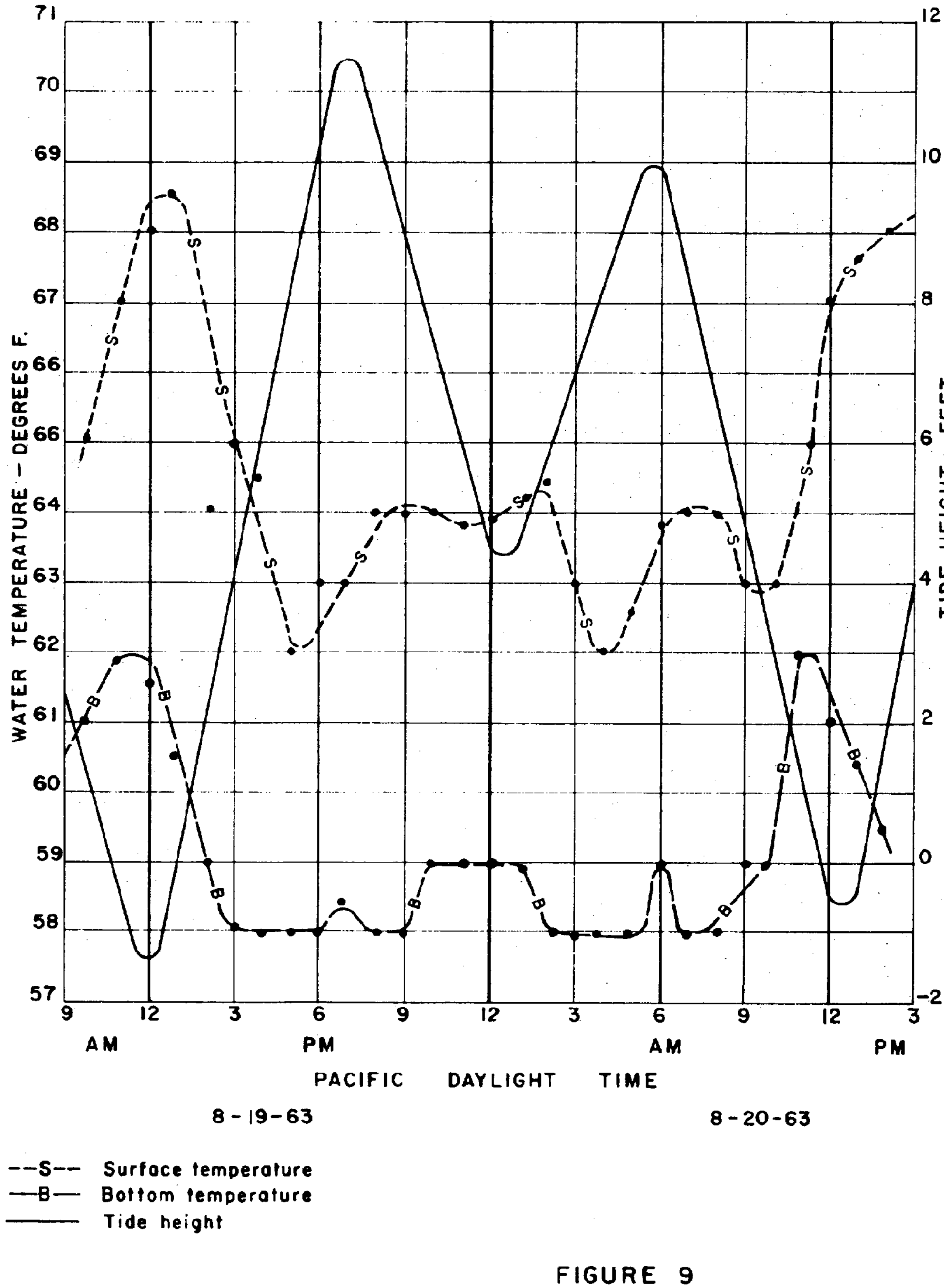

FIGURE 9

FLUCTUATIONS IN SURFACE AND BOTTOM WATER TEMPERATURE WITH CHANGES IN TIDE HEIGHT-STA. 5

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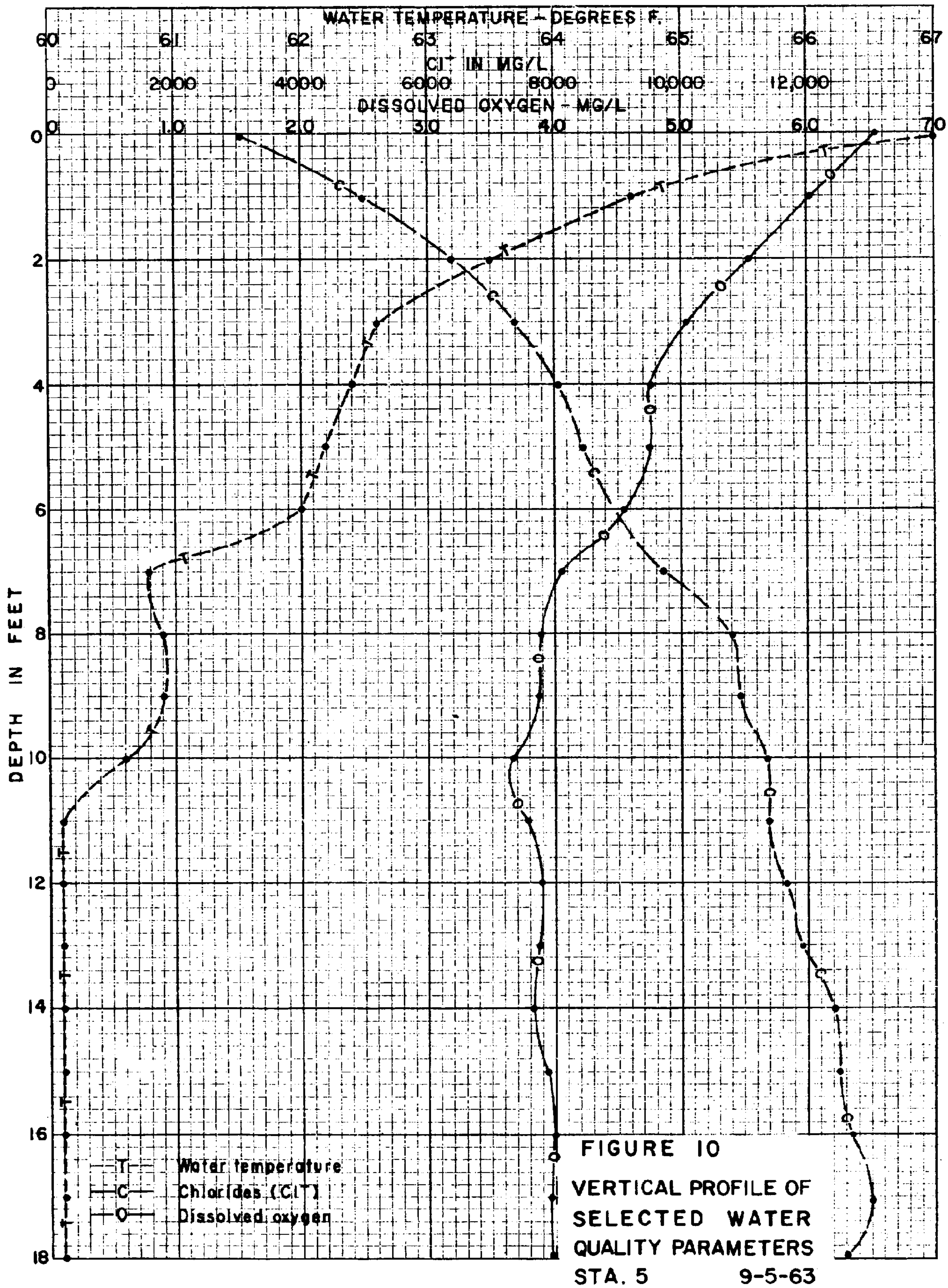

FIGURE 10

VERTICAL PROFILE OF SELECTED WATER QUALITY PARAMETERS

STA. 5 9-5-63

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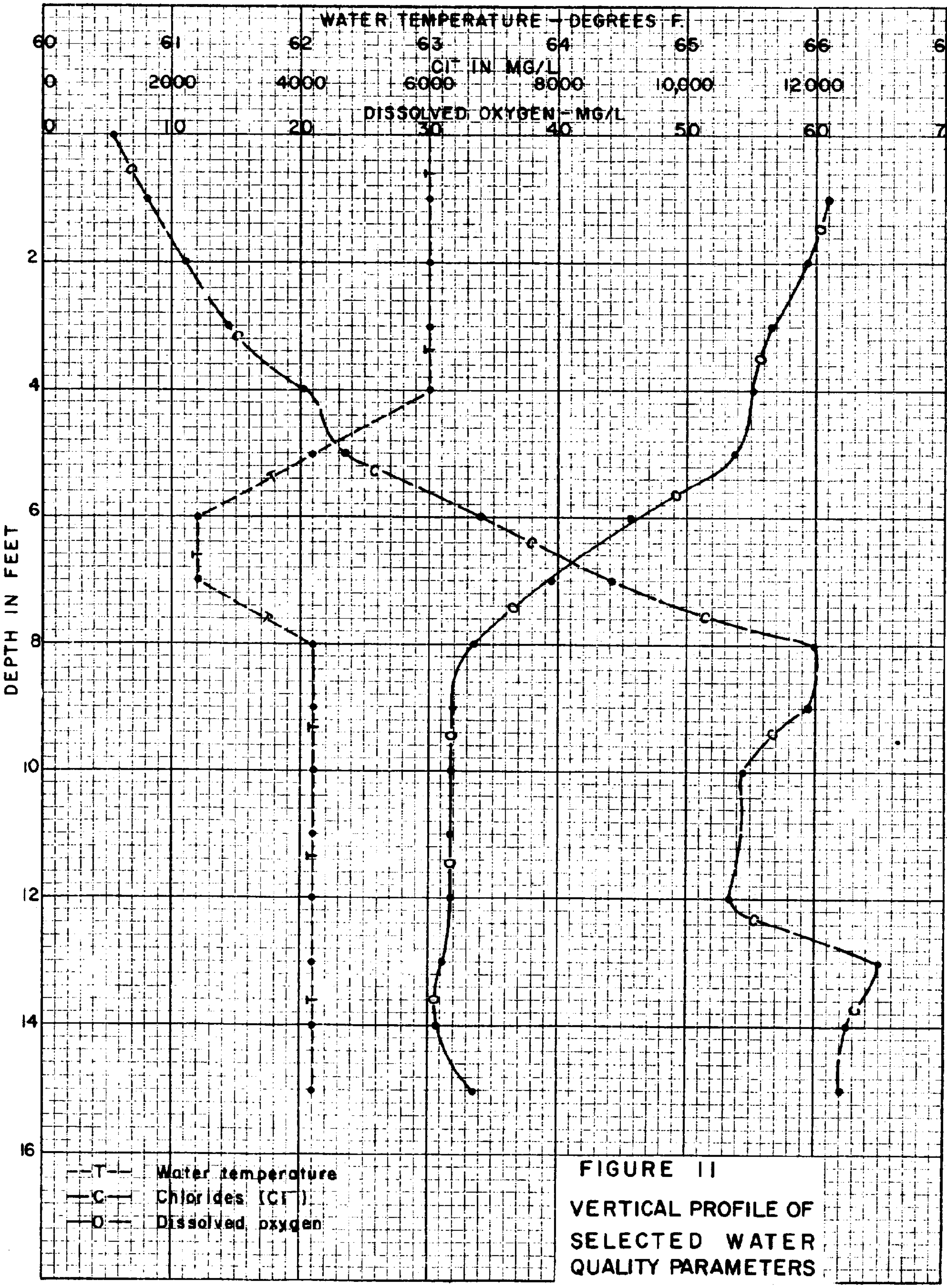

FIGURE 11

VERTICAL PROFILE OF SELECTED WATER QUALITY PARAMETERS

STA. 5 9-16-63

by the PCC for maintenance of fish life, was 3 feet on September 5 and 5½ feet on September 16. During this period of investigation, samples taken near the bottom at Station 5 at lower low water accurately reflected changes in Duwamish water quality to within five feet of the surface. These data also show that although adequate dissolved oxygen is present in the surface layer for the maintenance of aquatic life, the majority of the water column at this location is deficient in DO. Despite this dissolved oxygen deficiency, the chinook salmon run into the Green River, which took place during the period of low DO, was one of the best on record (approximately 30,000 fish). Apparently these fish were not deterred by the low DO concentrations in the Duwamish Estuary, or they detected and consequently avoided the low DO zone by utilizing the surface water. Additional research to determine the effect of oxygen-deficient water on the movements of adult salmonids through the use of sonic tagging is presently being planned. A joint program under the supervision of the University of Washington College of Fisheries and Metro is being contemplated.

DAILY SAMPLING

In order to maintain surveillance of daily changes in river conditions, and with the information obtained from the diurnal studies, a program of daily sampling was begun. The sampling was designed to encompass lower low water and the two-hour period immediately following. As can be seen in Figures 4 and 5, there is a short lag between the time of low water and the time of minimum DO near the bottom. It was believed that a two-hour sampling period commencing at lower low water would cover this lag, thus insuring that the minimum daily DO values would be obtained.

The sampling program was begun on August 15, and continued through October 31, 1963. The results of six daily sampling runs are shown in Figure 12. This Figure presents the surface and bottom DO concentrations in mg/l for randomly selected days during the two-month sampling period. The minimum bottom DO concentration appears to be well bracketed by this sampling procedure. The corresponding minimum surface DO concentrations were not bracketed nearly as well. Figures 4 and 5 indicate that the minimum surface DO value occurs well in advance of the minimum bottom value. This was not believed to be a serious sampling problem, because the surface DO did not reach a critical level and bottom DO's are the major concern as far as the preservation of aquatic life was concerned.

Tidal Influence

The daily minimums in bottom DO, the corresponding surface DO, and the depth of the tidal prism in feet are plotted in Figure 13. In this instance, the "tidal prism depth" is calculated as the algebraic difference between the sums of the two high waters and the sums of the two low waters each day. The volume of the tidal prism was not calculated as it was believed that the depth of the tidal prism was directly proportional to volume, i.e., the estuary has essentially vertical sides. Not only does tide influence, to a large extent, the daily fluctuations in water quality, but it also affects weekly fluctuations as is shown in Figure 13. The periods of minimum tidal prism depth were found to be the periods of poorest water quality. The magnitude of the tidal prism depth

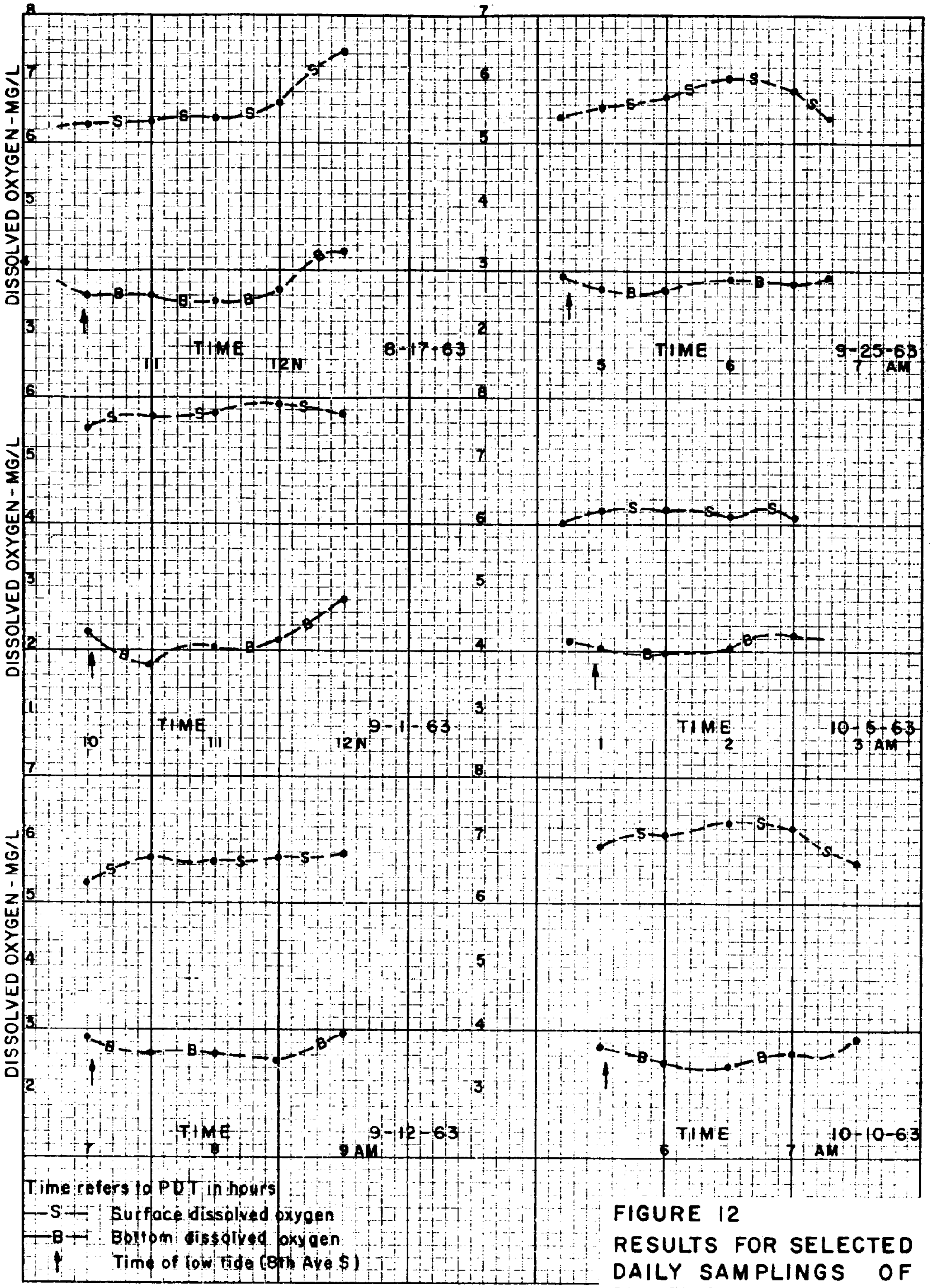

FIGURE 12

RESULTS FOR SELECTED DAILY SAMPLINGS OF DISSOLVED OXYGEN - STA. 5

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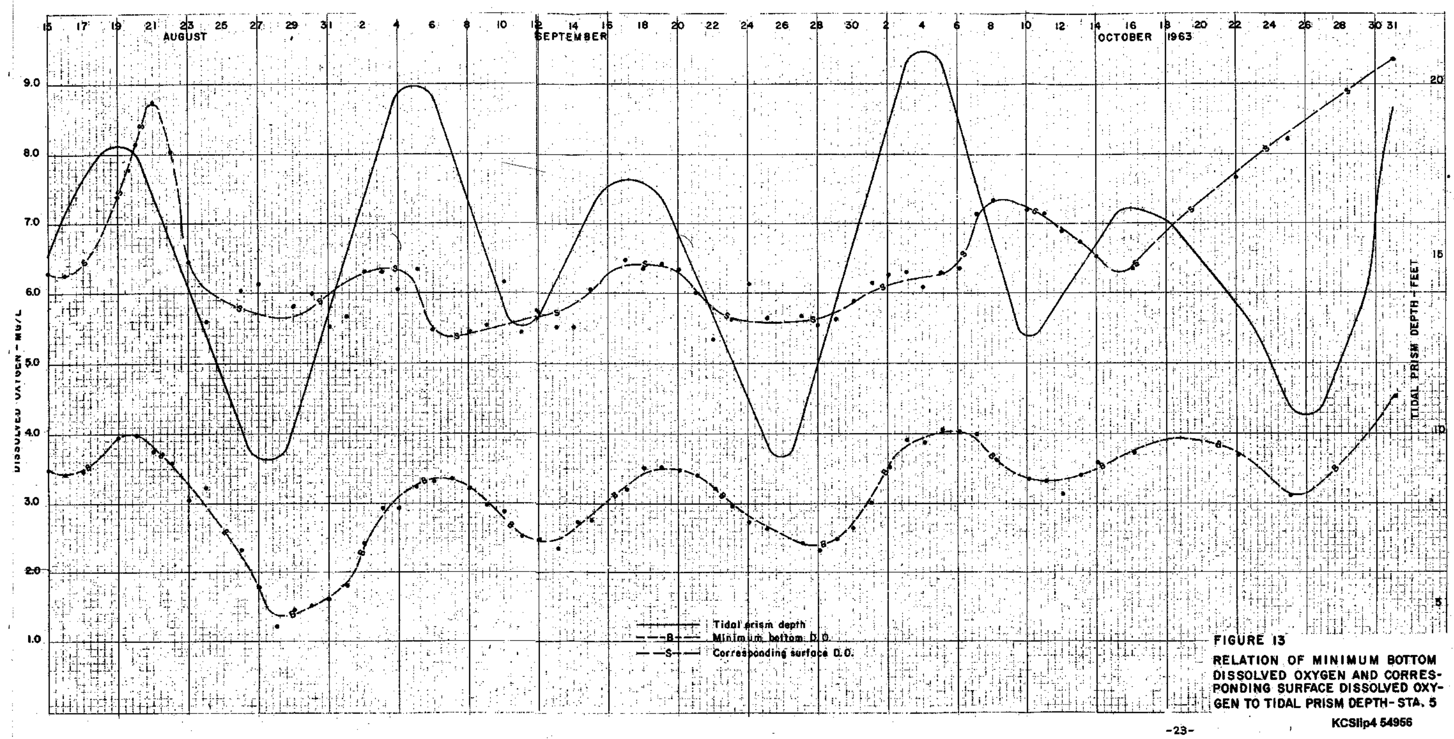

FIGURE 13

RELATION OF MINIMUM BOTTOM DISSOLVED OXYGEN AND CORRESPONDING SURFACE DISSOLVED OXYGEN TO TIDAL PRISM DEPTH - STA. 5

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is particularly important in regulating weekly changes in minimum bottom DO concentrations. The same is true of surface DO concentrations, although the daily fluctuations are much greater, partly due to the aforementioned time difference between the minimum near the surface and low tide and partly due to the influence of other surface factors, i.e., sunlight, waste dispersion in the surface zone, variation in surface water temperature, river flow, etc.

Figure 14 presents the relationship between minimum chlorides near the top and bottom and the stage of the tide. As was the case with bottom DO, bottom chlorinity is closely regulated by the tide. The bottom chlorides are minimal during periods of maximum tidal fluctuations, indicating the influence of vertical mixing at the upstream of river end of the estuary. Minimum surface chlorides appear to be quite uniform and the only major influence of the tide occurs during periods of minimum exchange; i.e., more salt water stays in the estuary as indicated by increased surface chlorinity during this period.

Fresh Water Influence

Another important consideration is the influence of the Green River in regulating estuary water quality parameters, especially near the surface. The lack of vertical mixing in the lower estuary, as indicated by Figures 10 and 11, negates the effect of fresh water influence on bottom water quality during low-flow periods. Figure 15 records the relationship between surface DO (at the time of minimum bottom DO), tidal variation and instantaneous river discharge obtained from the Auburn gauging station of the U. S. Geological Survey. All curves have been fitted by eye in order to

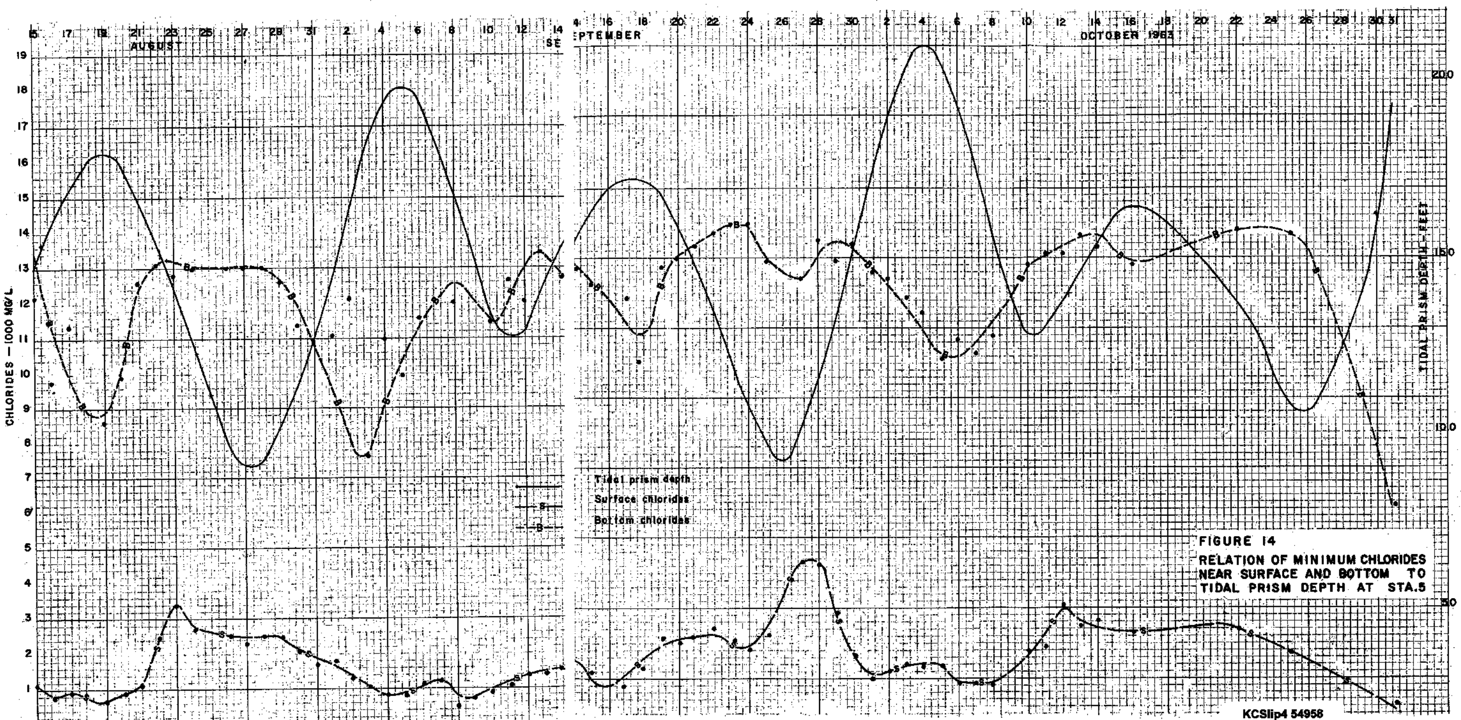

FIGURE 14
RELATION OF MINIMUM CHLORIDES NEAR SURFACE AND BOTTOM TO TIDAL PRISM DEPTH AT STA.5

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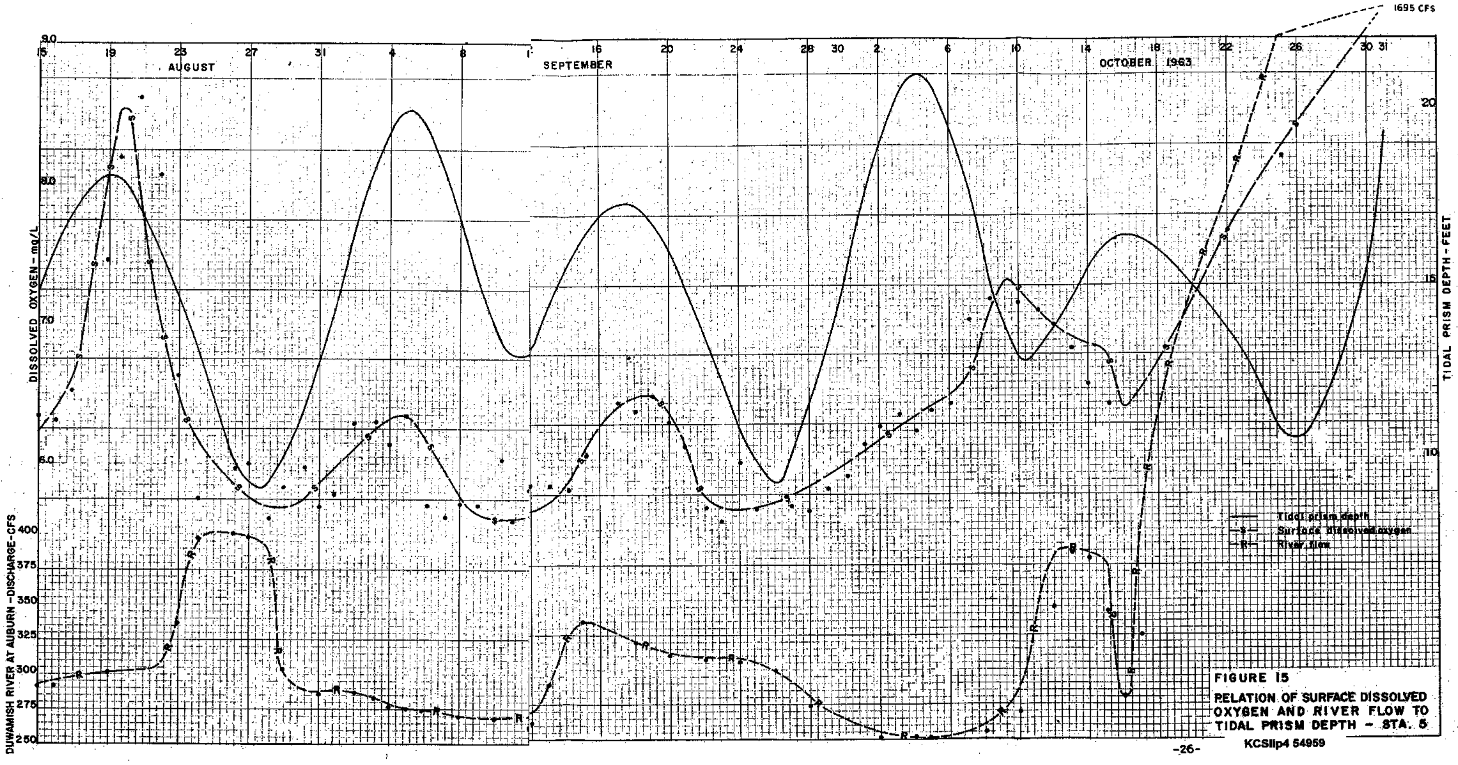


FIGURE 15
RELATION OF SURFACE DISSOLVED OXYGEN AND RIVER FLOW TO TIDAL PRISM DEPTH - STA. 5

KCSlip4 54959

eliminate short-term fluctuations. At one point during the most critical DO period in August (see Figure 13) the possibility of increasing the flushing in the lower estuary and consequently increasing the DO concentration by using additional flow from Howard Hansen Dam on the upper Green River was suggested. Such a release was authorized by the U. S. Army Corps of Engineers and for three days (August 22, 23 and 24) the river flow was increased by 40% (100 cfs). It is apparent from Figure 15 that the additional release, although it contributed approximately 40,000 pounds per day of DO, had little effect on the surface DO in the lower Duwamish Estuary. Since there is only limited vertical mixing at Station 5, the influence of the release of additional water was not expected to effect the bottom DO concentration, and no such effect was experienced. An 85 second-foot increase in flow occurred from September 10 to 12, but again there appeared to be only a limited relationship between the increase in flow and surface DO. The increase in DO obtained at this time was concurrent with an increase in tidal exchange; consequently, the relationship between increased flow and DO is obscurred.

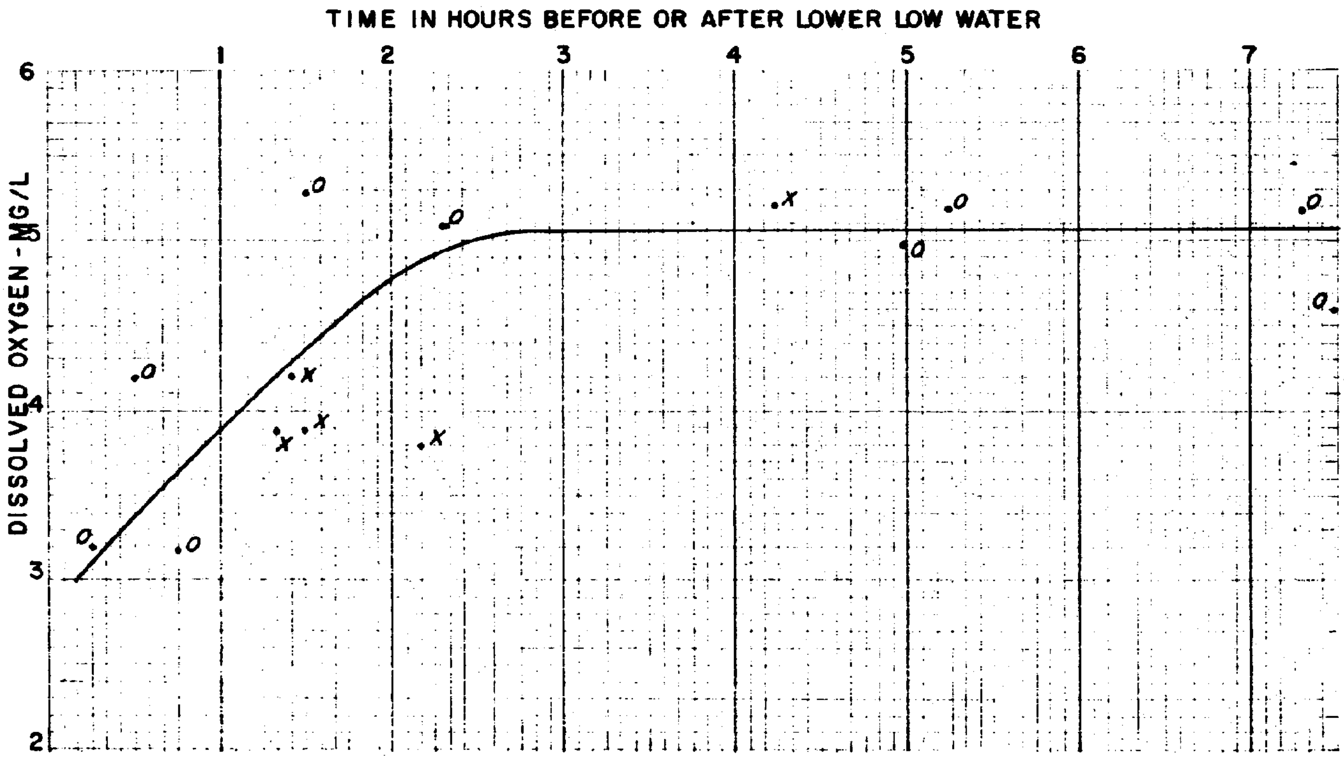
A considerable influence of the Green River was noted on October 17, when a five-fold increase in flow occurred following a heavy rain. This flow increase was definitely reflected in the chlorinity and dissolved oxygen values obtained on October 31, as is shown in Figures 13, 14, and 15. Surface DO at the time of minimum bottom DO increased to 9.3 mg/l, which was the highest surface value recorded during the three-month period of observation. At the same time, surface chlorides reached a minimum of 284 mg/l, the lowest level obtained. These surface phenomena are undoubtedly due to increased river flow.

Minimum bottom chlorides were also encountered with this five-fold increase in river flow, indicating that considerable vertical mixing was taking place in the upstream end of the estuary. Minimum bottom DO concentration on this date was 4.5 mg/l, which is a substantial increase over previous values. Tidal exchange heights were also increasing during this period, however, and a portion of this increase in minimum bottom DO concentration may have been due to the increase in tidal exchange, as is evident by the manner in which the bottom values continued to follow the tidal exchange curve.

It is apparent that a five-fold increase in river flow has an impact on surface water quality in the lower estuary, and to a lesser extent on water quality near the bottom. The benefits of such a marked flow increase cannot be expected to alleviate the summer conditions in the lower estuary, except during periods of unusually heavy summer rainfall.

EVIDENCE OF PREVIOUS WATER QUALITY PROBLEMS

In 1948, the Washington State Department of Fisheries reported DO concentrations of less than 5.0 mg/l at South Park (16th Avenue South). The question may be asked, "Were the low values obtained during the summer of 1963 peculiar to this particular summer, or have similar levels been occurring each summer for many years?" Figure 16 presents the relationship of bottom DO concentration at Station 5 to the time differential before or after lower low water, and appears to support the hypothesis that similar low oxygen levels have occurred historically. These data represent the



x 1961
o 1962

FIGURE 16

BOTTOM DISSOLVED OXYGEN CONCENTRATIONS AND TIME DIFFERENCE FROM LOWER LOW WATER STA 5

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SEA421290

results of weekly sampling trips during the years 1961 and 1962. Most of the low DO levels were obtained on days when the time of sampling at Station 5 approached the time of lower low water. The scattering of points about the line, however, indicates that DO concentration is not simply a function of tide, but is influenced by other factors.

WATER QUALITY PREDICTIONS

The ultimate goal of Metro's water quality monitoring program for the Green-Duwamish River is the prediction of changes in water quality so that the operation of the Renton plant can be regulated to meet changing conditions in the receiving waters. Many quantitative and qualitative variables will need to be considered in such predictions. Certain of these variables were studied during the summer of 1963, and the influence of three of these parameters is discussed below.

Green River

Based on the data accumulated by September 1 and knowing that a week of low tidal exchange was going to occur from September 24-28, a prediction was made that DO would fall to below 1.5 mg/l during this period. Identical tidal prism depths occurred on August 28 and September 26, yet the low DO in September (2.4 mg/l) did not approach the low of 1.2 mg/l obtained in August. River flow was higher during the critical August period (390 cfs) than in the September period (300 cfs); therefore, fluctuation in discharge could not be the explanation for the higher DO level obtained during late September.

Puget Sound

Another possible explanation for the difference in bottom DO's under similar tidal conditions might be a difference in the DO of incoming bottom water from Puget Sound. Figure 17 depicts bottom chlorides, DO's and temperatures obtained at Station 7 near the mouth of the estuary during the late summer of 1963. It shows that the DO of incoming Puget Sound water was higher during the critical August period than in September; still, the bottom DO in August reached a much lower level. Temperature differences between these two periods were very slight and chlorides varied only from 14,500 to 16,700 mg/l; consequently, the theory that differences in characteristics of incoming Puget Sound water were responsible for the observed difference in low DO at Station 5 must also be eliminated.

Sewage Diversion

During early August, it was necessary, because of sewer construction along East Marginal Way, to divert a substantial quantity of raw sewage into the estuary between Stations 4 and 6. This amounted to approximately 6,000 pounds of BOD per day that would normally have received primary treatment at the Diagonal Avenue treatment plant before discharge near the mouth of the estuary. When river conditions became extremely critical in late August, Metro urged the contractor to complete the construction work as quickly as possible, and by September 2, the additional raw sewage from this diversion was going back to the treatment plant. In addition, 490 of the 600 pounds per day of BOD from treated sewage that had been entering the river below Station 1 was diverted back

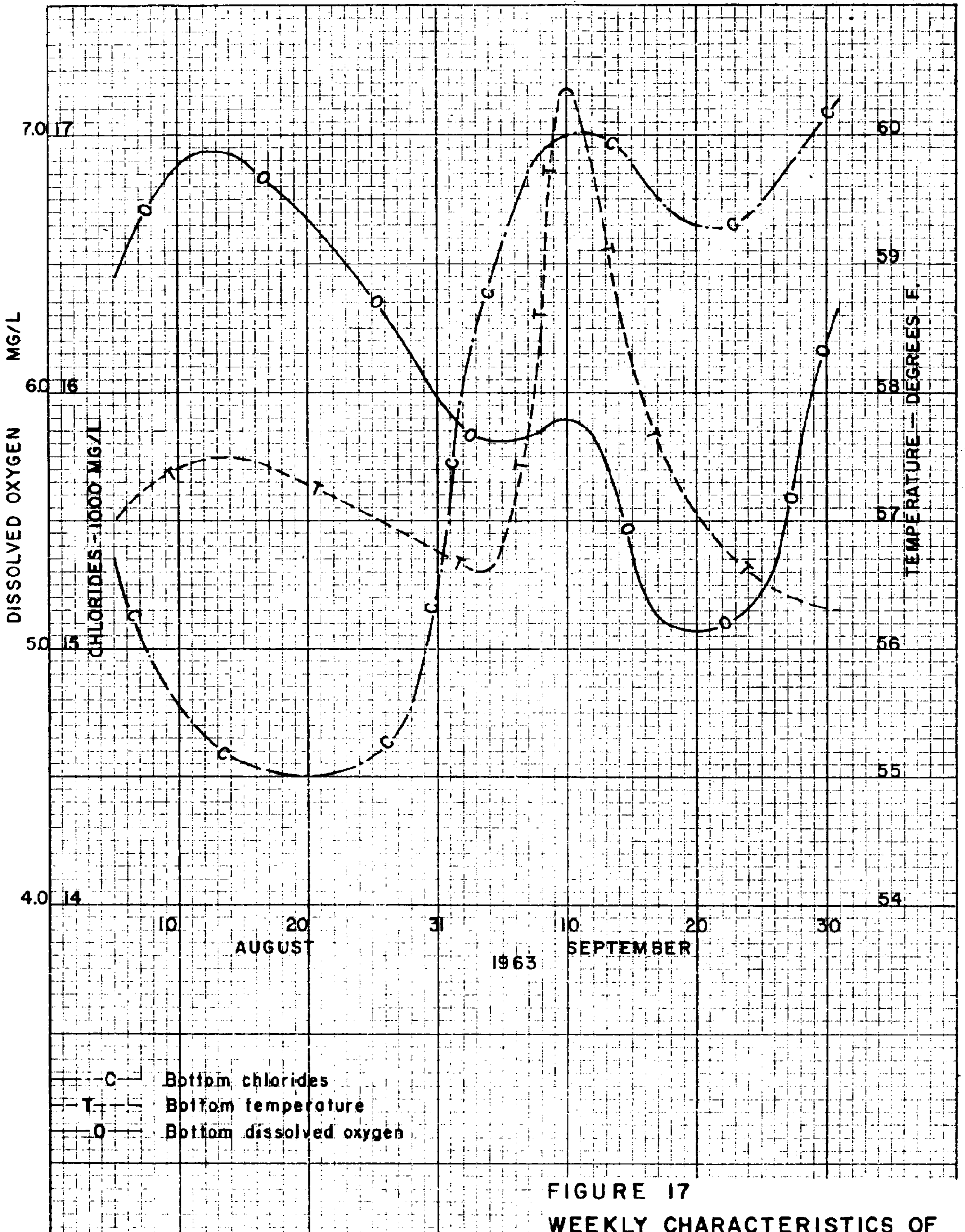

FIGURE 17

WEEKLY CHARACTERISTICS OF BOTTOM WATER NEAR THE MOUTH OF DUWAMISH ESTUARY - STA.7

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to Lake Washington as an emergency measure. The immediate increase in DO concentration shown in Figure 13 is believed to be due to the increased tidal exchange and not to the BOD removal, since it would take two or more days for the impact of this emergency measure to be felt at Station 5. The fact that the bottom DO did not fall as low on September 26 as it did on August 28, however, is believed to be due, at least in part, to the reduction in BOD loading to the lower estuary. It is doubtful that removal of the 490 pounds of BOD from the upper river had any measurable influence on surface or bottom DO conditions at Station 5.

The lack of influence in the lower estuary of wastes removed at Renton Junction would appear to be good evidence that loading at this point in the system from the new Renton treatment plant will have little impact on water quality in the lower Duwamish Estuary.

The day-to-day bottom DO concentration in the river could usually be predicted to within 0.5 mg/l by careful consideration of the previous DO values and the projection of maximum tidal exchanges. Eventually, when proper weight can be given to BOD removal from the lower estuary, and retention time and flushing characteristics have been determined, even more precise predictions can be expected.

SUMMARY AND CONCLUSIONS

The Green-Duwamish River system has historically played an important role in the industrial development of King County. This important river has, in the past, received little attention from the standpoint of maintaining water quality at an adequate level for all uses. The Municipality of Metropolitan Seattle is presently undertaking a program that will eventually result in adequate water quality throughout the Green-Duwamish basin.

The results that have been presented herein are for the portion of Metro's monitoring activities completed during the critical summer period, 1963, and should be considered as preliminary or probative studies. These studies will be continued and greatly expanded through the aid of four automatic water monitoring units to be installed early in 1964.

The results of Metro's first summer of intensive sampling has revealed the following findings which are believed to be of significant value:

1. The release of up to 100 cfs of additional water from Howard Hansen Dam was of little benefit in terms of alleviating the serious water quality problems in the lower Duwamish Estuary. This does not mean, however, that the added release of water did not benefit other important upstream uses of Green-Duwamish water, i.e., irrigation, domestic and industrial water supplies, and fisheries. The amount of water that appears necessary for adequate flushing will not be available during critical periods except during occasional heavy rainfall.
2. Preliminary studies during the critical summer period of 1963 have indicated that tidal exchange is one of the important factors in the regulation of Duwamish water quality. The influences of

volume of waste discharges, upwelling, river flow, and other factors studied appeared to be overshadowed by the influence of the tide. This conclusion is, of course, based on preliminary observations and may be modified at a later date as more information is collected.

3. Data collected thus far suggests that it will be possible to predict impending water pollution problems by projection of tidal prism information and by careful consideration of quantitative variables.
4. The removal of 490 pounds per day of BOD from Renton Junction on the upper river had no measurable effect on water quality in the lower estuary. The removal of a large quantity of untreated waste from the lower river may have been responsible for the improved conditions noted on September 28.
5. The continuation of data collection with automatic equipment will make possible the eventual prediction of long-term trends in water quality; will facilitate more precise and continuous measurements; and should provide a means of scheduling in-plant operation of the Renton Plant to coincide with changes in river conditions.

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